

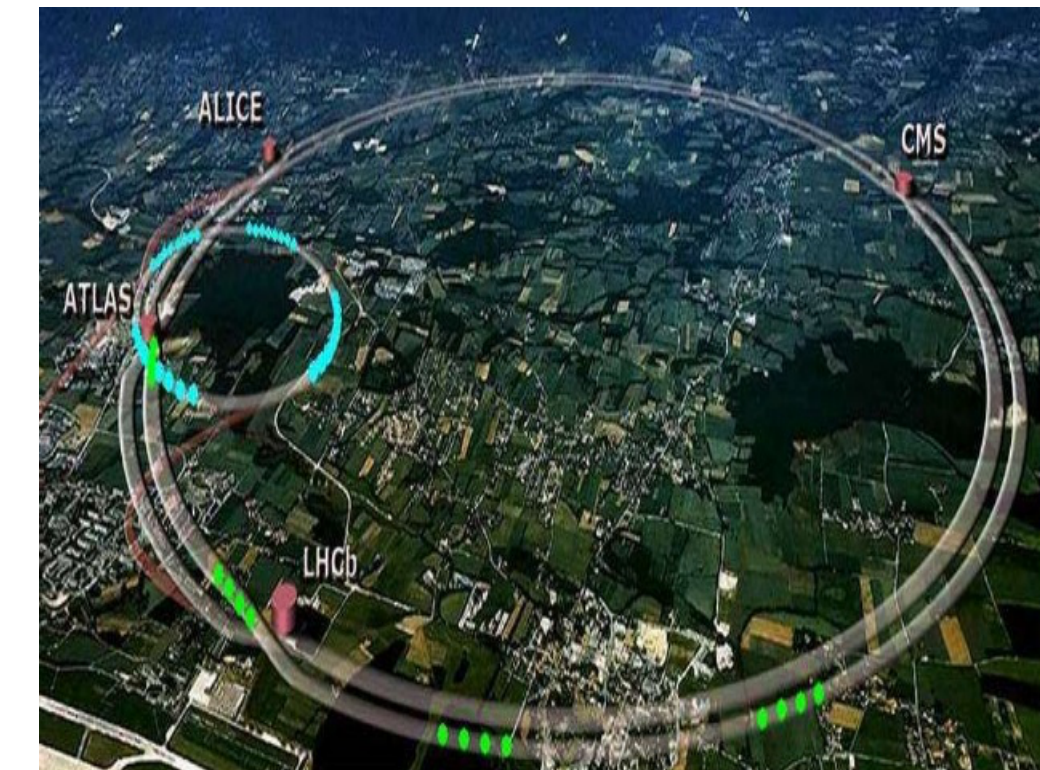
# Particle Physics with Quantum Sensors

Surjeet Rajendran,  
The Johns Hopkins University



# Grand Challenge of High Energy Physics

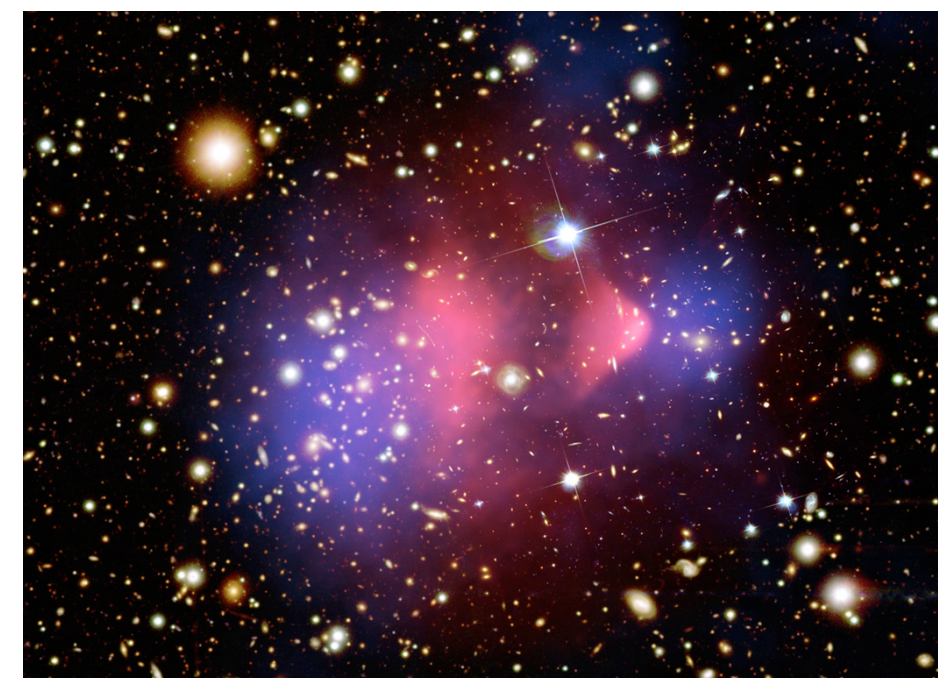
Standard Model experimentally established



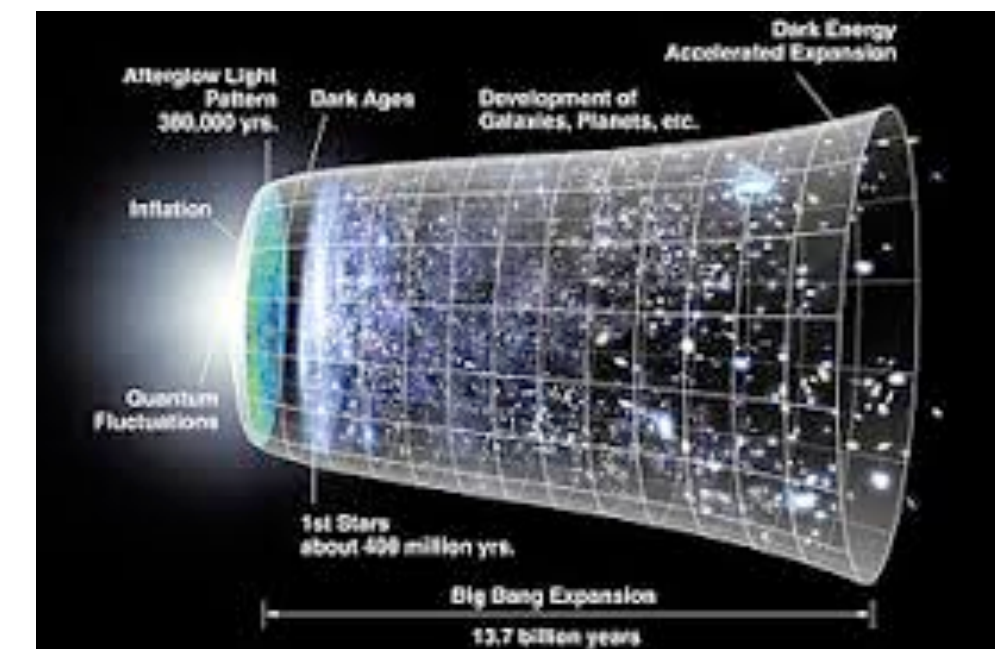
We **know** there is new physics out there



Matter?  
Universe?



Dark Matter



Dark Energy



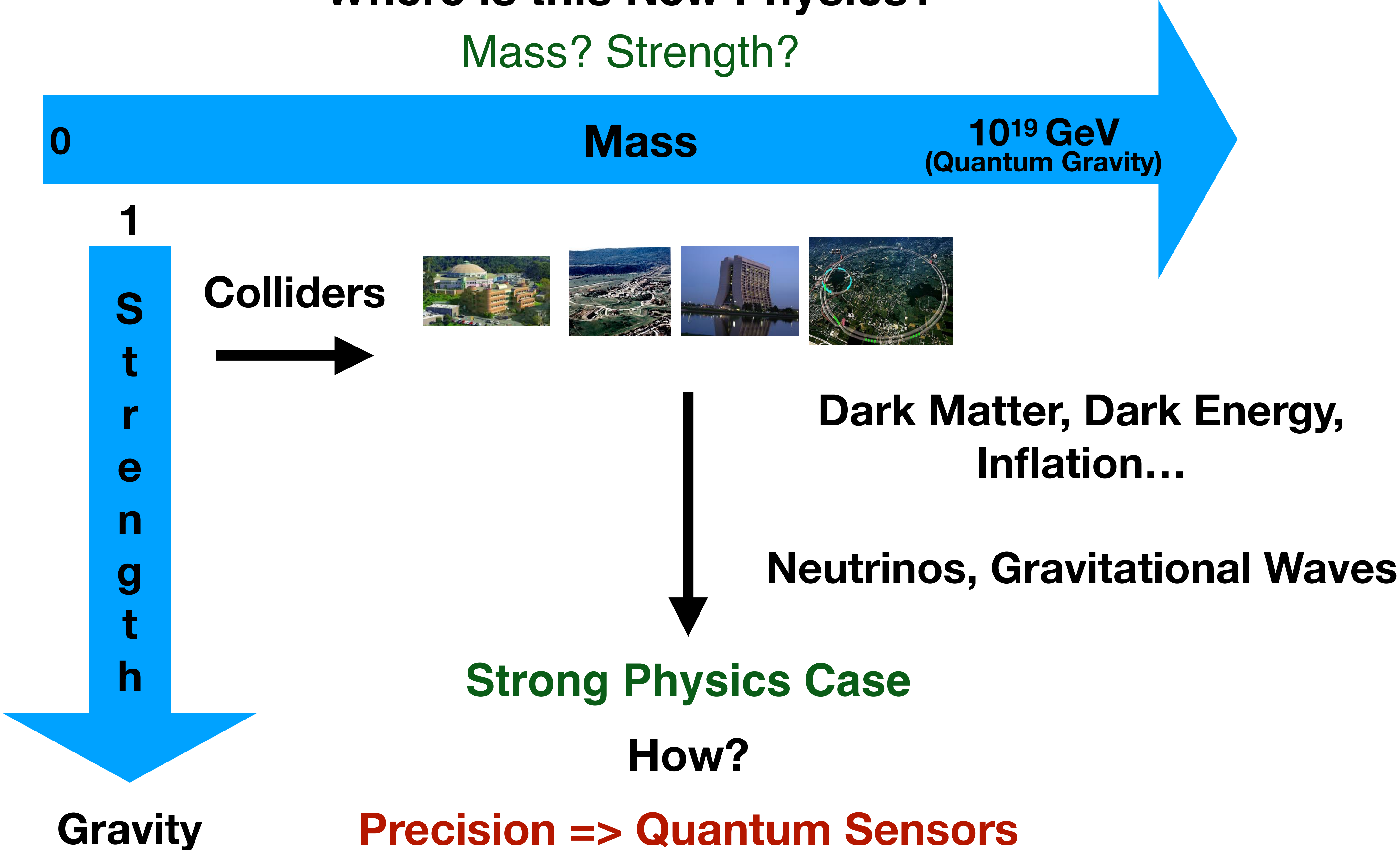
Hierarchy

Where is this new physics?



# Where is this New Physics?

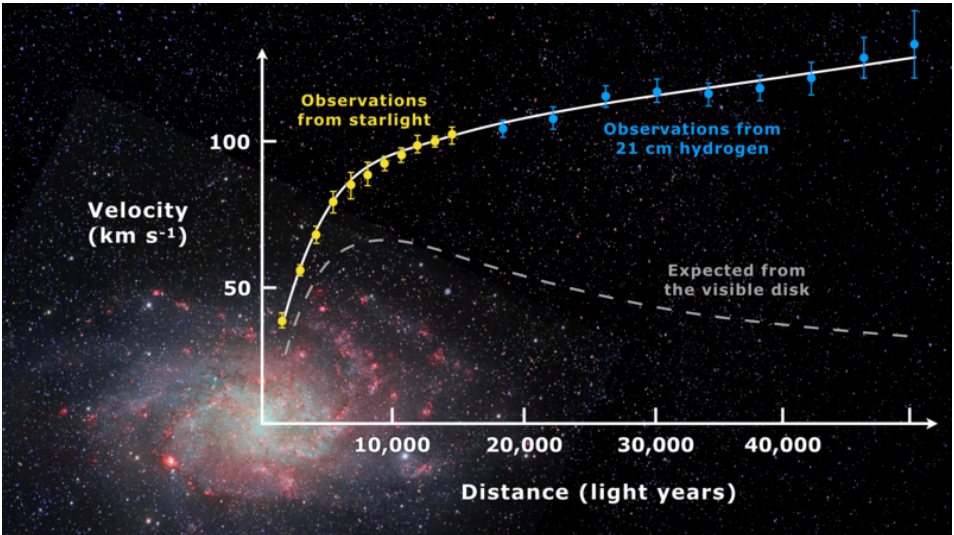
Mass? Strength?



# Quantum Tools for HEP

Questions

Tools



$\Lambda$

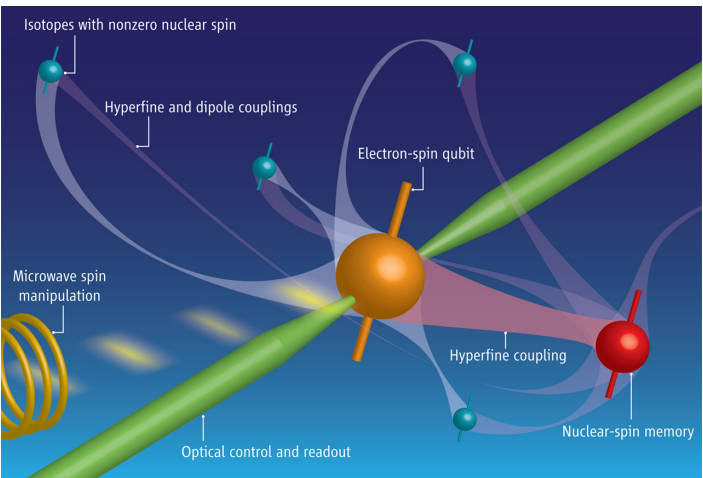
Dark Matter

Photons



Dark Energy

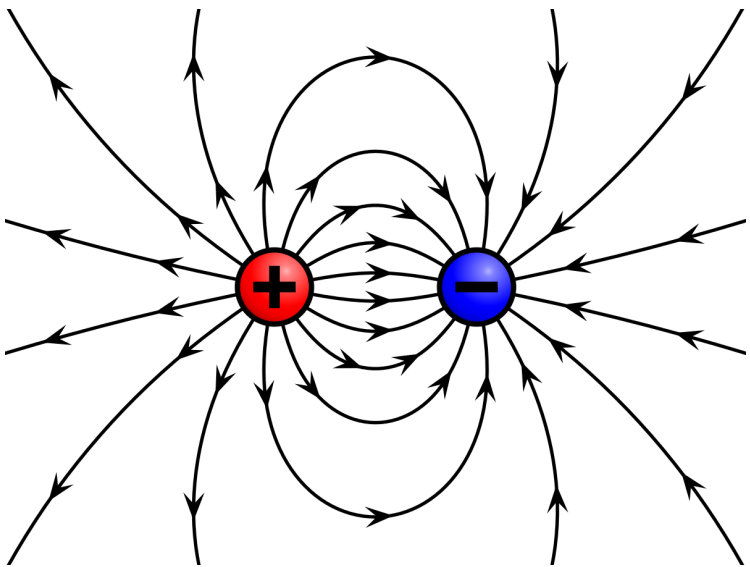
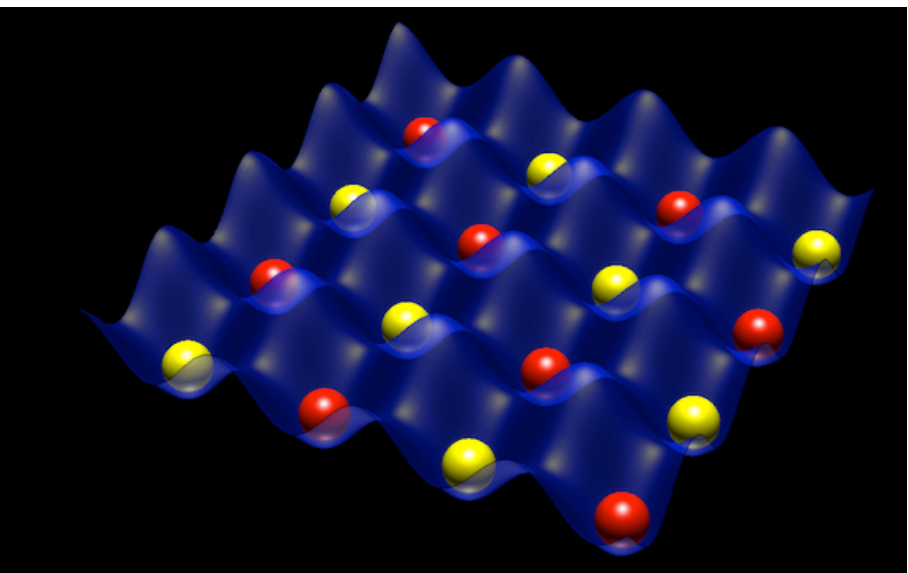
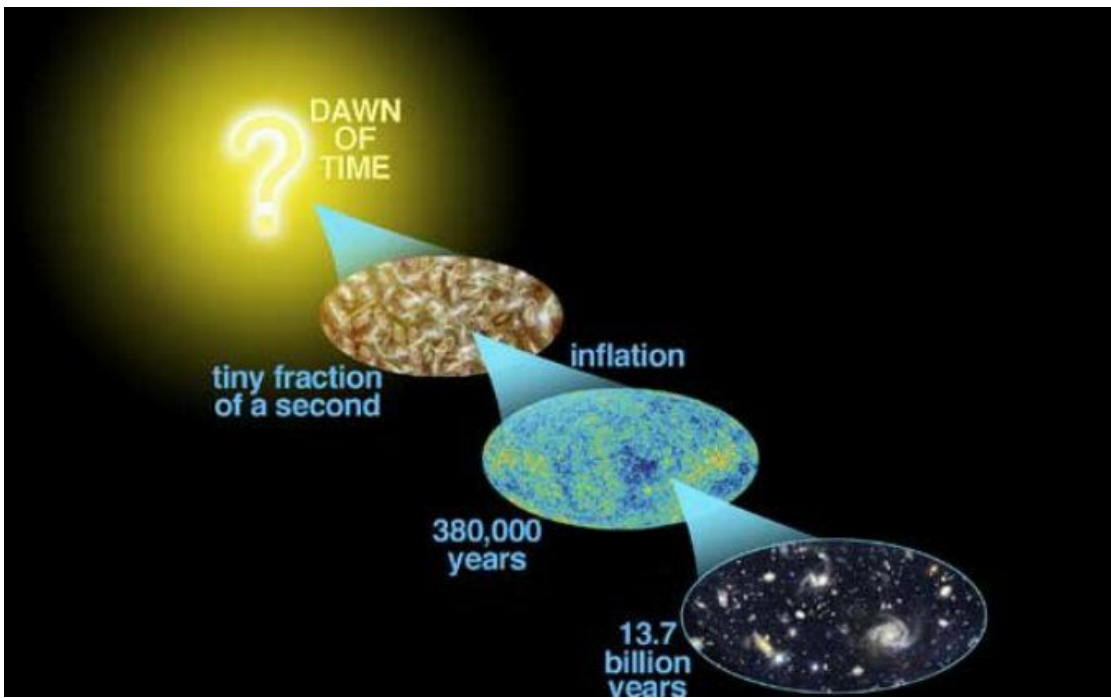
Spins



Opportunities?

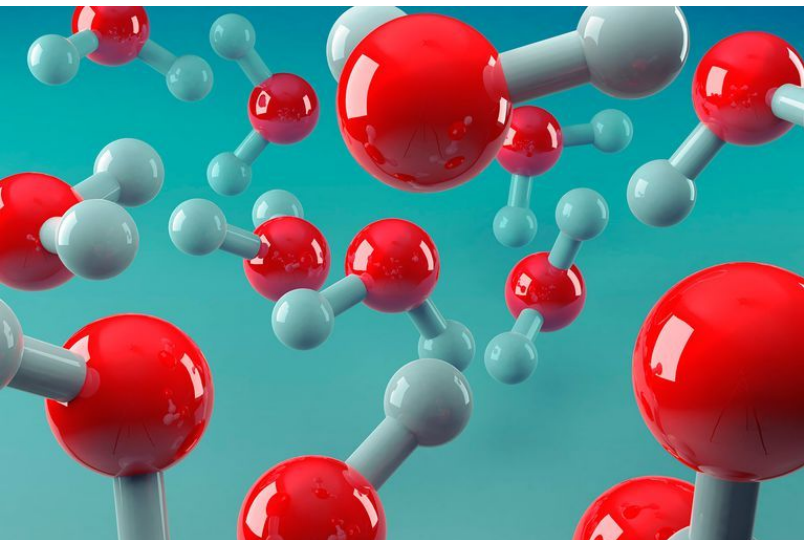
Inflation

Atoms



New Interactions/  
Symmetries

Molecules



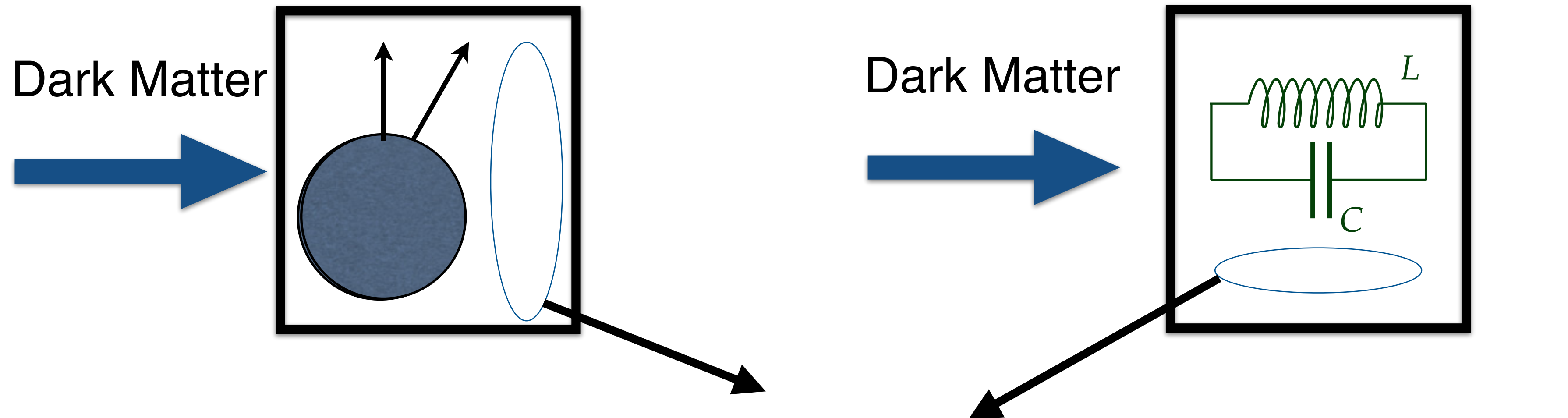


# Dark Matter

Study a/c effects of dark matter on electrons, nucleons and photons

(e.g. axion)

(e.g. axion, hidden photon)



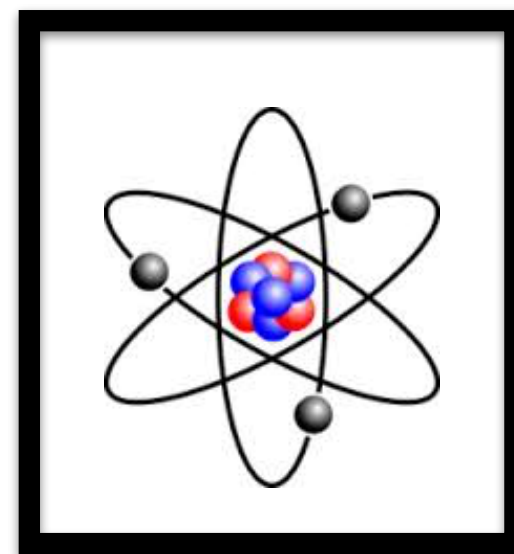
**SQUID Sensor** (neutrino masses?)

$$\text{Magnetic Field} \lesssim 10^{-16} \frac{\text{T}}{\sqrt{\text{Hz}}} \cos(m_a t)$$

Dark Matter



(e.g. relaxion)



Direct force on atoms, measure acceleration

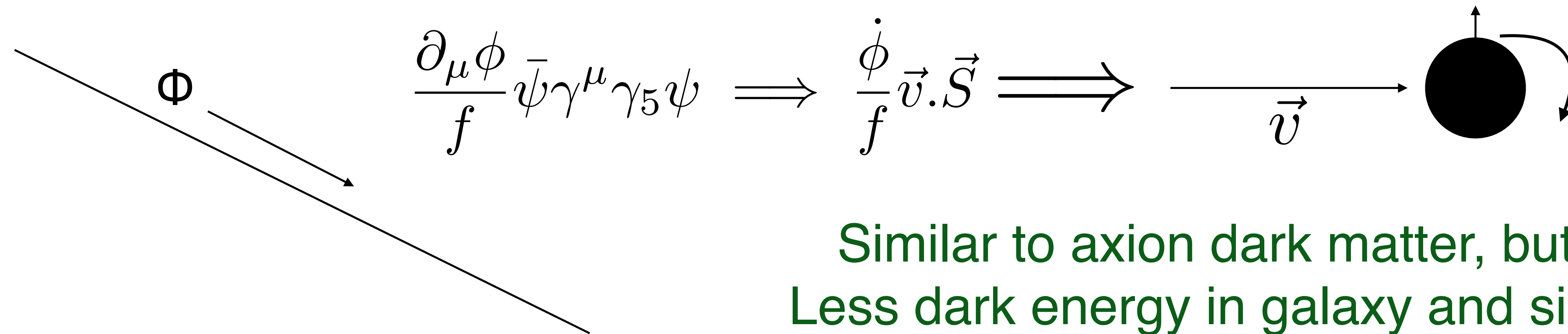
$$\text{Accelerations} \lesssim 10^{-13} \frac{\text{g}}{\sqrt{\text{Hz}}} \cos(m_a t)$$

Sensitivity scales with size (volume, time...)

# Direct Detection of Dark Energy

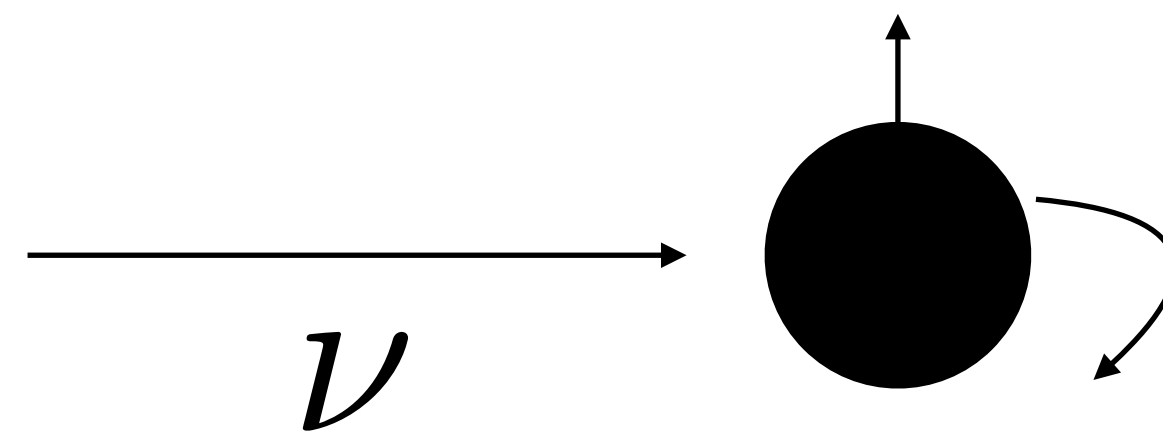
What is it?

Constant? Does it have a kinetic energy?



Similar to axion dark matter, but harder  
Less dark energy in galaxy and signal is dc

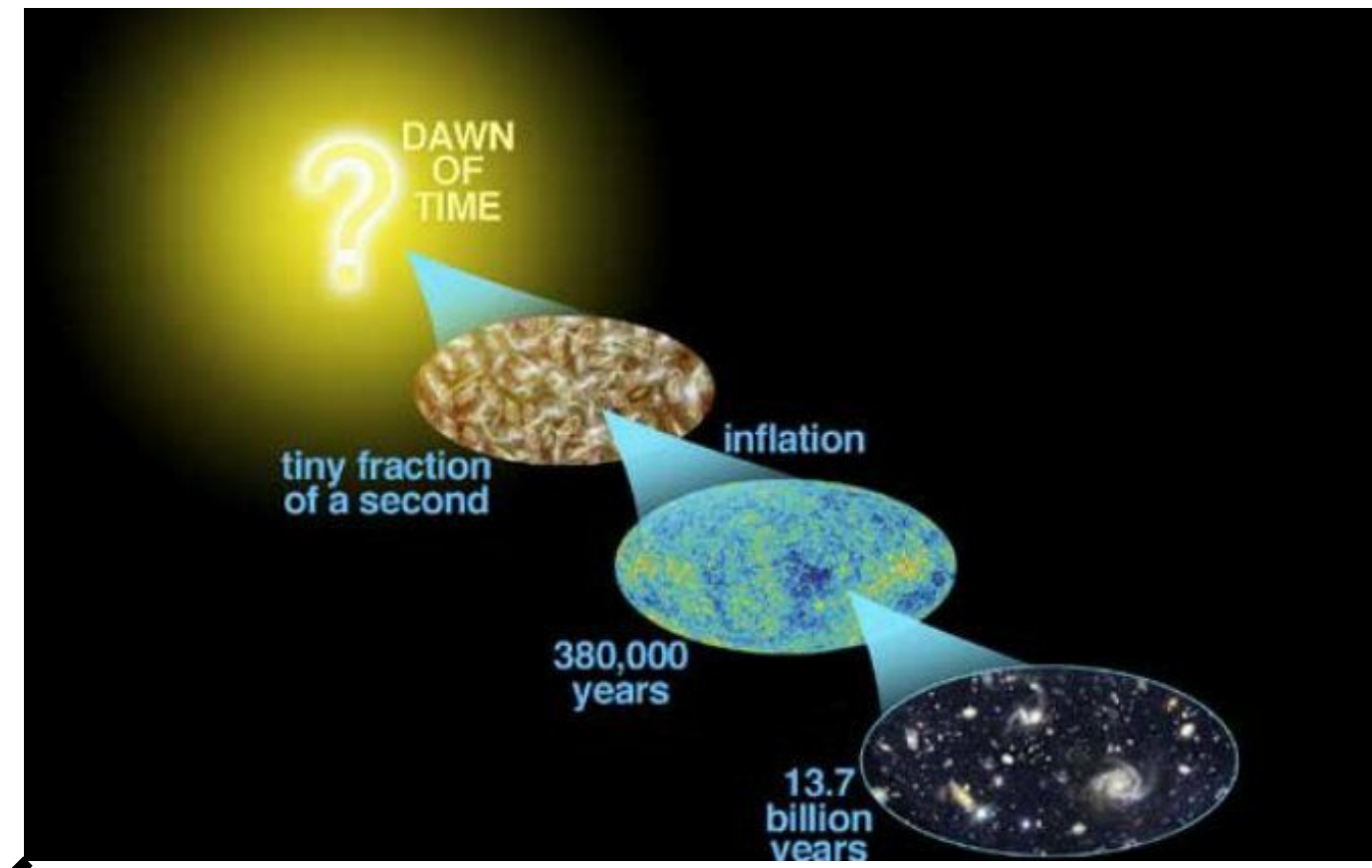
Bonus



Neutrino current not Energy.  
Calibrate reactor output + low  
energy neutrino detection

Enhanced Sensitivity with Quantum Acceleration

# Inflation



Direct

Gravitational Waves

Two Frequencies: CMB, 1 - 10 Hz

Probe Inflationary Potential  
(optical and atom interferometry)

Indirect

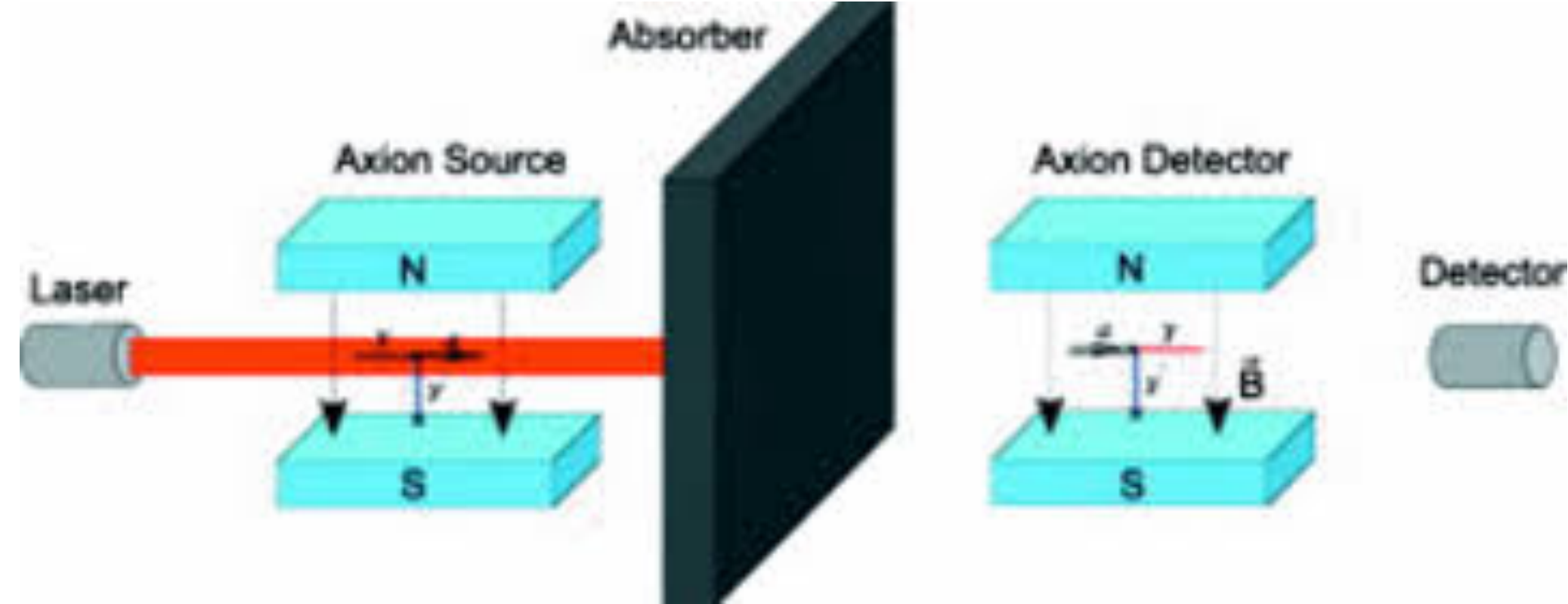
Produce ultra-light particles

Lab detectable dark matter  
(e.g. vector bosons)

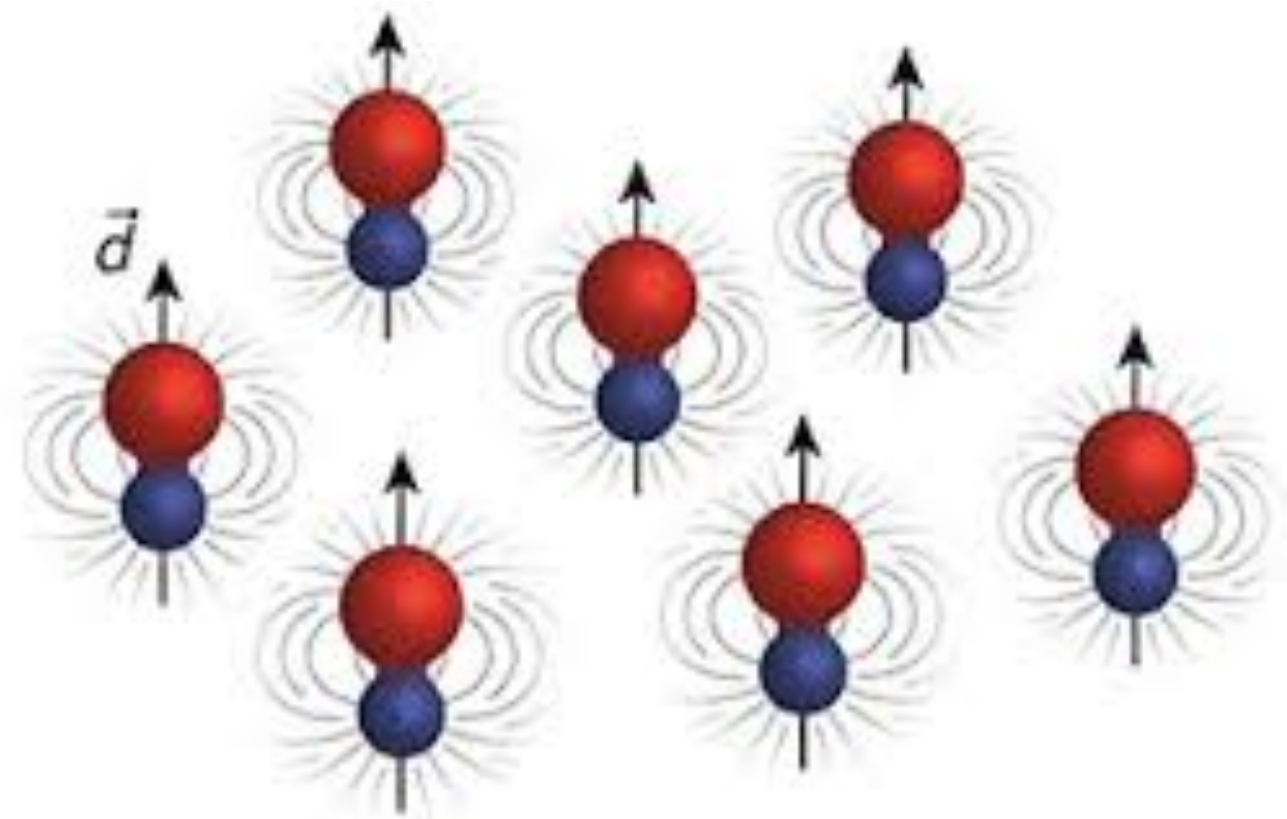
(electromagnetic sensors,  
interferometers)



# New Interactions and Symmetries

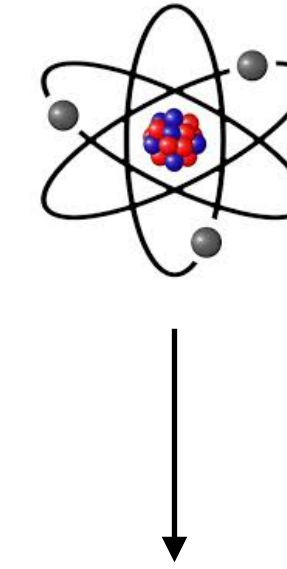


Photon Qubits/Single Photon Detectors



CP Violation? Dark Matter?

Ultra-cold molecules with actinides



Optical and Atom Interferometry



# Outlook

Dark Energy

Dark Matter

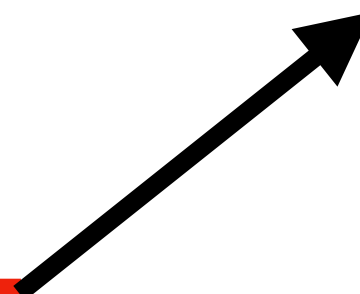
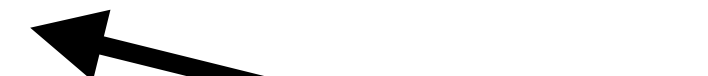
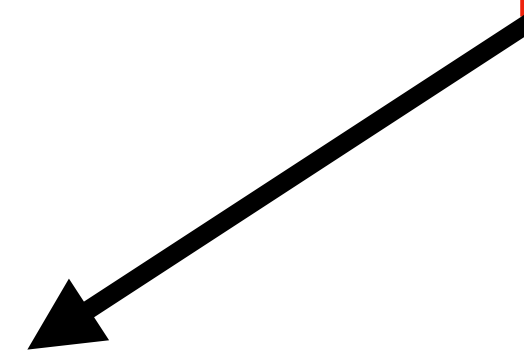
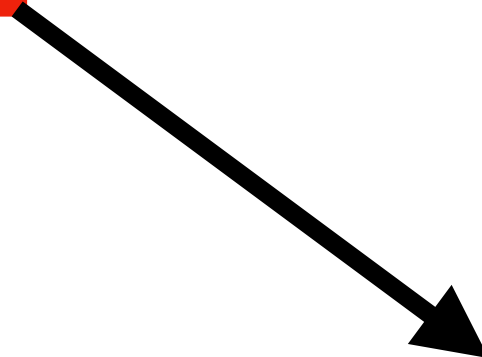
Inflation

Weak Effects

Quantum Sensing

New Interactions and  
Symmetries

Neutrinos

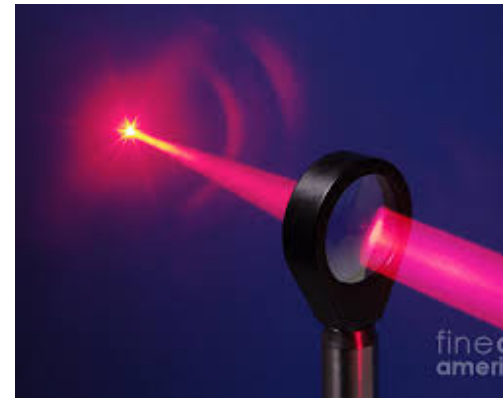


# Roadmap

Tools

Near

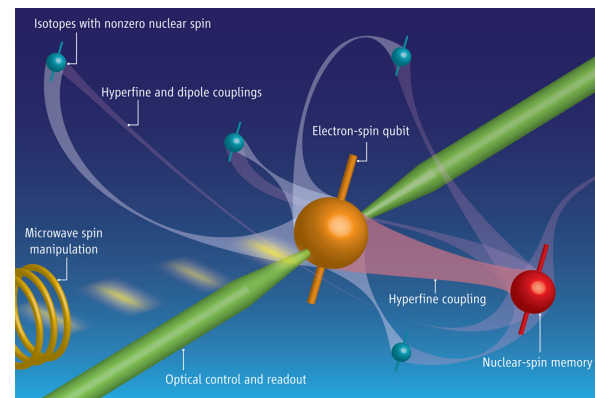
Ultimate



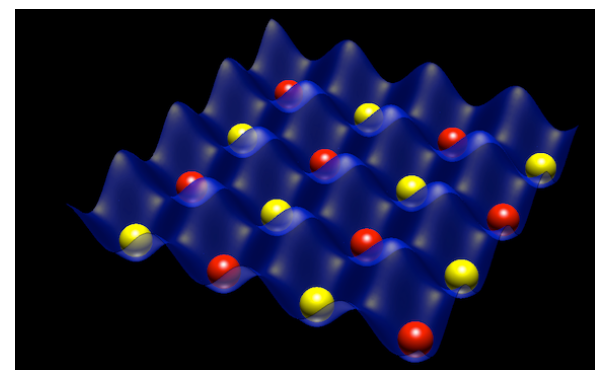
Dark Matter  
New Interactions



Inflationary Relics



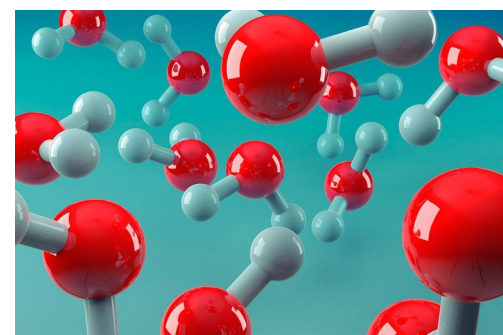
Dark Matter → Dark Energy → Neutrinos



Dark Matter  
New Interactions



Gravitational Waves  
(e.g inflation)



$\theta_{\text{BSM}}$  → Dark Matter →  $\theta_{\text{SM}}$

Technologies are a direct contribution to the National Quantum Initiative  
QIS contribution to major HEP goals